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Coastal Exploitation Throughout Marismas Nacionales Wetlands in Northwest Mexico

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Abstract

The consequences of human exploitation on wetlands remain unresolved for many regions. Marismas Nacionales wetland in Northwest Mexico is a Ramsar site and a Biosphere Reserve at Mexico. By integrating literature sources, fisheries data, and field studies, this study shows how long-term coastal exploitation has contributed to subsequent declines in fishery resources and the wetland health. Oysters declined in prehistoric times and potentially recovered during the Spanish occupation. Further, overexploitation of oyster banks in the mid-19th century diminished oysters' populations by early 20th century. Then, inshore fishing cooperatives flourished and exploited shrimp and finfish. These fisheries seemed sustainable until outboard motors and nylon nets populated estuaries. Government subsidies and free-market policies of late 20th century exacerbated fishing effort and disrupted social organization of fishing cooperatives which lead to widespread illegal and unsustainable fishing practices. Currently, the seemingly subtle shifts in artisanal fishing techniques have modified Marismas' food webs. These results can help develop conservation guidelines for wetlands ecosystem services and be a reference for managers in other countries where long-term data of wetlands exploitation is limited.

Keywords

wetlands, coastal exploitation, small-scale fisheries, Northwest Mexico

Introduction

Long-term exploitation of coastal fishery resources is difficult to investigate in developing countries because information remains scarce (Andrew, 2007; Pauly, 2006). This limitation has been most successfully overcome by using a historical ecology approach, which can help allow scientists overcome issues associated with "shifting baseline" syndrome, and calls for the incorporation of nontraditional data to inform fishery management (Pauly, 1995). Historical and other unconventional data can be used to determine past abundance, exploitation, and decline of coastal resources (Jackson, 1997), and broadening our understanding of sustainable fisheries as a function of human population size, cultural values, technology, and recovery times for marine resources (Hardt, 2009; Lotze et al., 2006; McClenachan, 2009; Cramer, Jackson, Angioletti, Leonard-Pingel, & Guilderson, 2012; McClenachan, Ferretti, & Baum, 2012).

Marismas Nacionales (hereafter Marismas) is one of the largest mangrove forest on the Pacific coast of North America, located on the western Mexican coastal plain, in the southern region of Sinaloa and northern border of Nayarit, bounding the eastern shore of the Gulf of California (Flores-Verdugo, Gonzalez-Farias, Blanco-Correa, & Nuñez-Pasten, 1997; Figure 1(a)). The biologically diverse coastal wetlands of Marismas had abundant inshore fisheries since pre-Columbian times (Foster & Gorenstein, 2000), like other estuaries worldwide (Jackson et al., 2001; Lotze et al., 2006), and while

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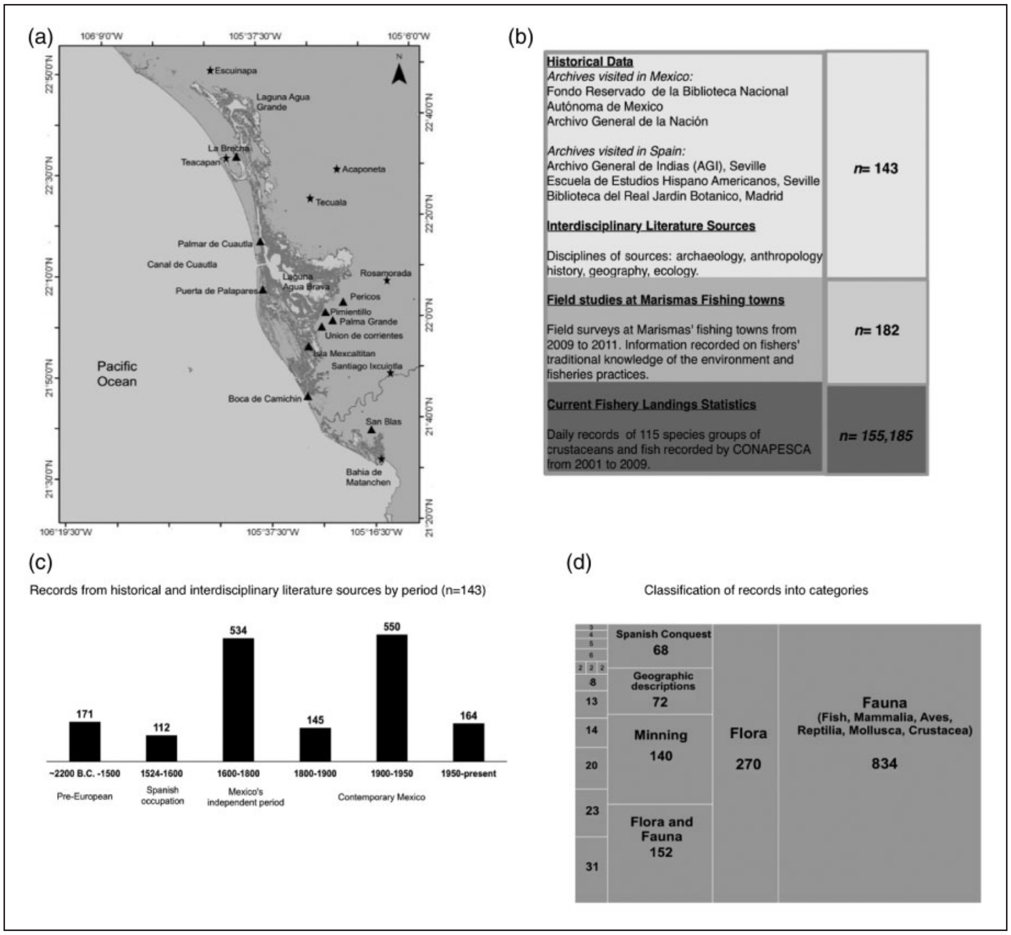


Figure 1. (a) Marismas Nacionales and the spatial distribution of population centers (stars), surveyed fishing communities (triangles), and mangrove cover (darker gray); (b) Interdisciplinary data used for this study; (c) Records from historical and interdisciplinary literature sources by period; (d) Classification of records into categories. The categories with more records were Flora and Fauna. Categories with lower number of records included: natural disasters, archaeological sites, anthropogenic impacts, agriculture, marine commerce, historical towns, among others.

heavily exploited in the past, it remains one of the most important fishery regions along the Pacific coast of Mexico (Aburto-Oropeza et al., 2008; Erisman et al., 2011).

Sáenz-Arroyo, Roberts, Torre, Cariño-Olvera, and Hawkins (2006) first documented the past abundance of marine fauna in the Gulf of California during the 16th to 19th centuries using historical testimonies of travelers. Whales, turtles, and large fish were bountiful but are now largely gone, and recent overfishing in shallow coastal areas throughout the region evince ‘‘fishing down the food web’’ practices (Sala, Aburto-Oropeza, Reza, Paredes, & Lopez-Lemus, 2004).

Nevertheless, there is no integrated long-term history of exploitation of coastal wetlands in the Gulf of California, a document fundamental for developing conservation actions (McClenachan et al., 2011). Information from this study provides an overview of the ecological potential of Marismas, which could overcome current anthropogenic threats if properly managed, and provides an overview of the human modifications to estuaries, overfishing, and destructive fishing practices (Berlanga-Robles & Ruiz-Luna, 2006; Carvalho et al., 2002; Cruz-Torres, 2001; Liedo, Cruz-Torres, & Morán-Angulo, 2007).

In addition to guidance in regional fisheries, this study is relevant to food security and the conservation of biodiversity on a global scale. Over the coming decades, there will be an increasing global demand for seafood (Godfray et al., 2010). At present, 57% of worldwide fish stocks are fully exploited and 30% of the remaining fish stocks are overexploited (Food and Agriculture Organization of the United Nations, 2011). This incredible demand for marine resources has led to a suite of unsustainable extraction behaviors and exploitative labor practices (Brashares et al., 2014). Our analysis of fishing and the associated changes of inshore fishery resources of Marismas over the past 4,500 years provides insight into the global problem of local populations adapting to depleted coastal food webs. Our results also shed light on how perceptions of fishing practices and consumption of fish, shellfish, and shrimp have changed.

Methods

We obtained historical data from archives in Mexico and Spain (Figure 1(b) to (d)) and complemented the information with more recent interdisciplinary literature sources collected through the interlibrary loan system at the University of California, San Diego. The results were compiled in a single database based on 143 literature sources. From these references, we extracted 1,676 unique records related to fisheries and natural resources. Literature sources were then complemented with 182 field surveys taken throughout fishing cooperatives of 10 fishing towns of Marismas Nacionales (Table 1). For each location, fishers' surveys documented information about fishers' households, fishing practices, mangrove knowledge, historical changes in their catches, and their perception of the fishing cooperative system. Pilot surveys were conducted in November 2010, which allowed us to be known in the region, and to establish key community contacts at fishing cooperatives.

Final surveys were conducted from February 1 to March 28, 2011. The surveys' templates can be downloaded from: http://www.nadiarubio.com/portfolio/phd-research-on-coastal-ecosystem-services/#Portfolio. Surveys were conducted respectfully by acknowledging local customs and minimizing disruption to people's routines (Bunce, 2000). For guidelines on sample size considering the trade-offs in resources available (time, personnel, and money), we used guidance from Pollanc (1998).

Historical trends in coastal exploitation in Marismas were established upon data grouped into six periods based on key historical events (Table 2). For each period, we gathered information on the types of fishing gear employed as well as the habitats and animals exploited. Generic and family identifications were resolved to the extent possible based on published taxonomies (Froese & Pauly, 2011).

Descriptions of past faunal communities were also compared with landing statistics from 2001 to 2009 in a database recorded by the Mexican National Commission of Fisheries and Aquaculture (CONAPESCA) personnel (for details see: Erisman et al., 2011). This includes 155,185 daily records of 115 species groups of crustaceans and fish that were classified into three landing categories (for details see: Rubio-Cisneros, Aburto-Oropeza, & Ezcurra, 2016), grouped according to their life cycle and habitat distribution as adults (Robertson & Allen, 2008; Froese & Pauly, 2011; Appendix 1).

Results

Pre-European

Archaic period (7000 B.C.–2500 B.C.). Mexico's west coast was an important center of Pre-Hispanic cultural development (Sauer & Brand, 1932; Scott, 1968). In Marismas, the estuarine and coastal environment provided habitat for hunter-gatherers that subsisted by harvesting mollusks (Mountjoy, 2000; Scott, 1968; Appendix 2). Archaeological findings show hundreds of shapeless mollusk mounds made of the discarded shells of Anadara sp. (a mangrove swamp and sandbar species; Foster, 2000). These shapeless mounds contrast with the unique semipyramidal shellmound structure ''El Cálon'' (estimated construction time 1750 B.C.) located near Laguna de Agua Grande. El Calon is 25 m high with a base of $79\,m \times 89\,m$. It was constructed by the piling of ~260–300 million edible shellfish, mainly *Anadara grandis*, which had never been opened for food (Shenkel, 1971). Shellfish of diverse ecological

Table 1. Information of Fishing Cooperatives That Were Surveyed at Marismas Nacionales.

Location of fishing cooperative	Latitude	Longitude	State	Municipality	Main fisheries for each fishing cooperative
Pericos	22.05	105.35	Nayarit	Rosamorada	finfish
Pimientillo	22.02	105.41		Rosamorada	finfish
La Tovara Embarcadero	21.53	105.25		San Blas	tourism
Mexcaltitán	21.9	105.47		Santiago Ixcuintla	oyster, shrimp, and finfish
Boca de Camichín	22.35	105.53		Santiago Ixcuintla	oyster and shrimp
Palmar de Cuautla	22.26	105.63		Santiago Ixcuintla	oyster, shrimp, and fish
Puerta de Palapares	22.12	105.65		Santiago Ixcuintla	shrimp and fish
Union de Corrientes	21.98	105.42		Tuxpan	shrimp and finfish
Palma Grande	21.99	105.39		Tuxpan	fish and shrimp
La Brecha, Teacapán	22.55	105.7	Sinaloa	Escuinapa	shrimp and fish

Note. See map in Figure 1(a) for details.

Table 2. Summary of Major Characteristics for Each Time Period, Shades of Green Denote Habitat Quality (High to Low) for Each Period.

		Marismas Nacionales	
Time period	Date	Lagoon-estuarine ecosystem (southern Sinaloa and northern Nayarit)	Coastal ecosystem (San Blas)
Pre-European (1–6)	7000 B.C.–2500 B.C. (Archaic)	Small bands of individuals subsisting by harvesting large quantities of shellfish.	
	2500 B.C.–900 B.C. (Pre-Classic)	Coastal plain flooding.	Exploitation of fish, shellfish and tetrapods (Table S2)
	200 A.D.–900/1000 A.D. (Classic)	Agriculture is the main subsistence activity; seafood is a staple food.	Practice of coastal deep water shell fishing suggestive of a deep-water shellfish industry.
	1000 A.D.–1523 (Post-Classic)	Hundreds of shell middens composed of billions of shellfish were accumulated in 600 years.	Oyster harvesting along coastline. Oyster middens are rare or absent.
		Oyster meat was an important export item among tribes. Exploitation of diverse fishery resources.	
		Land abandonment ≈1200 A.D. related to landform development and possible overexploitation of oysters.	
		Coastal plain gradually resettles, marine resources had a respite.	
Spanish occupation (7–8)	1523 (Spanish contact)–1810	Natives mainly exploited the abundant fishery resources. Mining, salt extraction, agriculture and livestock were the main economic activities.	
			1769, San Blaswas the busiest port in the Pacific coast.
Mexico's independent period (9–10)		Inshore fisheries were open access, plentiful and obtained with simple gear.	
	1810–1909	Mid 1800s thriving trade in smoked oysters. Late 1800s Asian traders develop an international oyster and shrimp export market.	Downfall of San Blas port. Agriculture and livestock, the main economic activities.
	1910–1949	State-owned inshore fishing cooperatives flourish and had exclusivity for fishing shrimp. Political-economic bossing promotes shrimp smuggling. Mexico's offshore fleet gains importance for exploitation of offshore shrimp fishery.	
Contemporary Mexico (12–15)	1950–1980	Proliferation of outboard motors and nylon nets in estuaries lead to overexploitation of finfish. Bivalve populations decline, shark and sea turtle fisheries intensify. Opening of the artificial Canal de Cuautla. Changes to fisheries policies promote dismantling state-owned inshore fishing cooperatives.	
	1981–Present	New fisheries policies favor large-scale fisheries and expansion of shrimp farms. Regional discontent promotes overfishing and unsustainable fishing practices are widespread. Mexico promotes conservation of inshore environments.	

Note. Periods of low (gray) and high (purple) population numbers are highlighted. Sources given below each time period.
(1) Shenkel, 1971, 1974; (2) Mountjoy et al., 1972; Mountjoy, 1974; (3) Feldman, 1976; (4) Cumbaa, 1973; (5) Kelly, 2000; (6) Foster & Gorenstein, 2000; (7) La Mota y Escobar, 1602–1605, reprinted 1940; (8) Lázaro de Arreguí, 1621, reprinted 1946; (9) McGoodwin, 1973, 1979, 1980; (10) Inskeep, 1961; (11) Wing, 1969; (12) Cruz-Torres, 2001; (13) Liedo et al., 2007; (14) Covantes-Rodríguez & Beraud-Lozano, 2011; (15) Rubio-Cisneros et al., 2012.

environments (e.g., intertidal beaches, reefs, offshore waters) were also present in lower quantities at El Cálon. Unlike *A. grandis*, which is only found in low densities today, these other species are now absent from Marismas, which was under water 7,000 years ago (Foster & Gorenstein, 2000).

Pre-Classic period (2500 B.C.–900 B.C.). During the Pre-Classic period, inhabitants at Bahía de Matanchén used nets to dredge large quantities of *Aequipecten circularis*, a free-swimming scallop that inhabits depths of 11–65 m today (Appendix 2). The abundance of *A. circularis* in later archaeological records suggests development of a deep-water shellfish industry by 200 B.C. Lack of bone in the shellfish mounds suggests that fish and tetrapods were uncommon in the diet of these early inhabitants (Feldman, 1976; Mountjoy, Taylor, & Feldman, 1972). Along the coast of San Blas, populations systematically exploited shellfish, sea catfish, sea turtles, birds, crabs, and sea urchins (Mountjoy & Claassen, 2005). The northern region of Marismas experienced episodes of abandonment caused by flooding of the coastal plain (Foster & Gorenstein, 2000).

Classic period (200 A.D.–900/1000 A.D.). Coastal societies expanded and subsisted primarily on agriculture during this period (Foster & Gorenstein, 2000). San Blas inhabitants practiced agriculture on terraces built into the hillsides, but because of the proximity to the coastal plain and estuaries, there is archaeological evidence of fisheries exploitation (Mountjoy, 2000). Archaeological mounds from the Teacapán estuary revealed that fish (Ariidae, Haemulidae, Carangidae) and sharks (*Carcharhinus* spp.) were exploited. Numerous small fish fragments also suggest the use of mass-fishing techniques, either by very fine nets or poisoning (Cumbaa, 1973).

Post-Classic (1000 A.D.–Spanish contact). Throughout this period, the population continued to expand throughout Mexico's west coast. Billions of shellfish were extracted in Marismas and accumulated in approximately 628 shellfish middens and mounds distributed throughout the Teacapán estuary (Foster & Gorenstein, 2000; Figure 2(a) to (b); Appendix 3). The distinction between middens and mounds is based on the presence or absence of domestic refuse. Shenkel (1971) categorized these deposits according

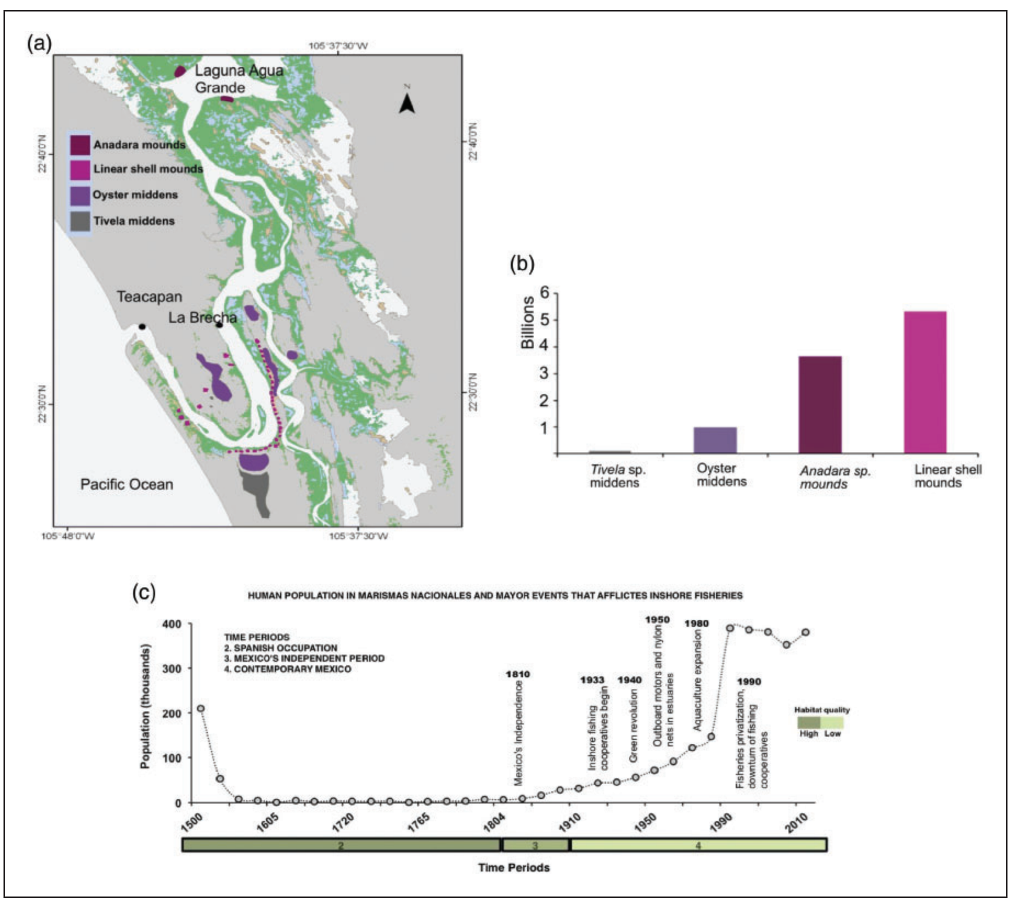


Figure 2. (a) Locations of shellfish middens; (b) number of shellfish estimated by Shenkel (1971); (c) Human population of Marismas Nacionales and major events that affected inshore fisheries.

to their shape and species composition in: Oyster and *Tivela middens* composed of *O. corteziensis* and *T. Byronensis*, respectively; linear shell mounds (up to 300 m long and 90 m wide, composed only of *O. corteziensis*); and *A. grandis* mounds.

Shenkel (1971) developed two models about prehistoric shellfish exploitation using dietary intakes of shellfish by early inhabitants over a 600-year period established by ceramic sequences. The models assume that shellfish were locally consumed by a population of ~5,000 people, or shellfish in the linear shell and *A. grandis* mounds were the refuse of a mollusk meat export, where a population of ~500 people was involved in harvesting and preserving mollusks. This last hypothesis is likely because oyster meat was an important item traded among west Mexico tribes (Meighan, 1969). Another interpretation is that locals may have granted harvesting rights to outsiders (Shenkel, 1971).

Nonetheless, we can only speculate on which of these two scenarios best represents post-classic exploitation, since the history of shellfish harvesting in Marismas is linked to the geomorphological processes of a migrating shoreline by long-shore currents, and estuarine alluviation (Connally, 1974). This geomorphological evidence and ceramic sequences suggest a break in human occupation in Marismas from ~900 to 1200 A.D. related to landform development (Foster & Gorenstein, 2000). However, overexploitation leading to local extinction of oysters or the overuse of agricultural land could also explain this temporary absence (Shenkel, 1971).

Spanish Occupation (1523–1810)

The Marismas region belonged to the Kingdom of New Galicia: gold and silver mining flourished until 30 years after the conquest, followed by other productive activities such as salt extraction, cattle raising, and fishing (Román-Gutiérrez, 1990). The Spanish conquest in the west (1530–1531) brought disease and harsh treatment of the natives, and lead to rapid depopulation of coastal areas (Anguiano, 1992; Figure 3(c)).

The introduction of cattle provided beef, which the Spaniards preferred to fish (La Mota y Escobar, 1602–1605). Demand for marine-based food greatly diminished, providing temporary relief to estuarine and coastal resources (Figure 2(a)). Further reduction in fisheries exploitation was attributed to another wave of depopulation in late 16th century when Spaniards migrated to central Mexico, discouraged by unsuccessful mining, severe floods, and war with natives (Román-Gutiérrez,

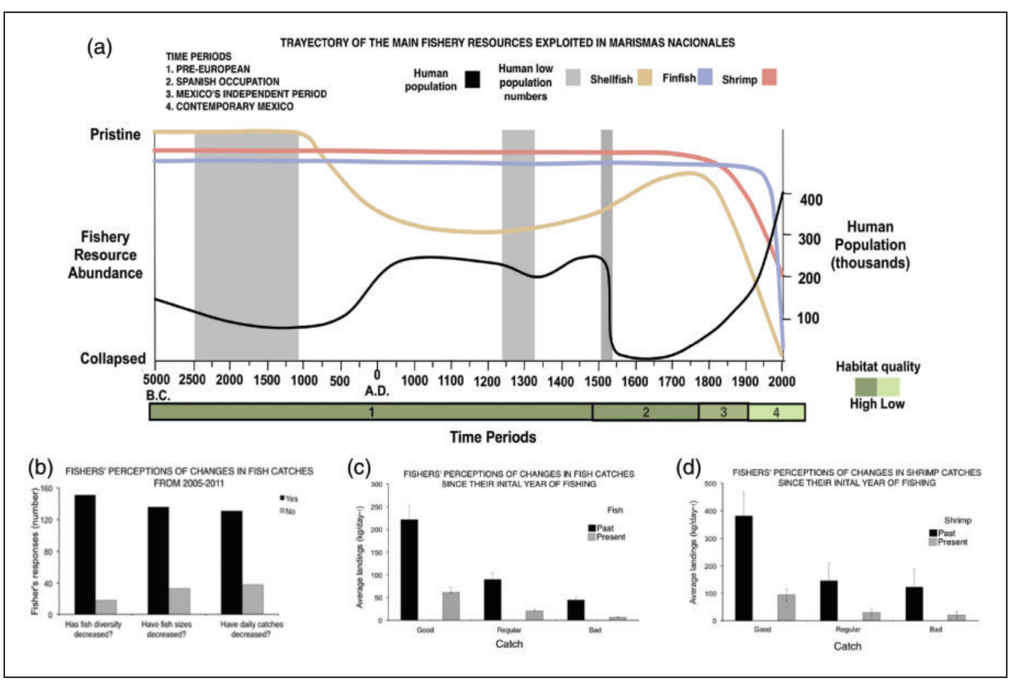


Figure 3. (a)Trajectory of the main fishery resources exploited in Marismas Nacionales. Shellfish (yellow), shrimp (orange), and finfish (blue). The dark black line shows the human population. Periods of low human population numbers are highlighted in gray. Habitat quality is shown in shades of green; (b) Fishers' perceptions of changes in their catches from 2005 to 2011; Fishers' perceptions of changes in their catches since the year they initiated fishing (past) to the year 2011 (present): (c) fish catches (n = 59 fishers' responses) and (d) shrimp catches (n = 75 fishers' responses).

1990). Throughout the 17th and 18th centuries, few natives and mulatos inhabited Mexico's west coast (Láazaro de Arregui, 1621 [1946]); Archivo General de Indias [AGI], 1784–1785). As mining flourished again in the 18th century, populations increased but coasts were sparsely populated (AGI, 1786). A trade of salted fish among mining camps of New Galicia existed (AGI, 1792).

Additional natural history records exist through Spanish historical documents praising the rich and exotic biodiversity of Marismas (AGI, 1632; Table 4). This is detailed in Bishop Alonso de La Mota y Escobar's (1602–1605) writings, where the author meticulously illustrates native fishing practices using movable weirs of braided mangrove branches to fish across estuary channels. He recounts this fishery

Table 3. Major Technological or Gear Developments Over Each Time Period.

		Period	
	Pre-European	Spanish occupation	Mexico's independent period
		1523–1810	1810–1909
	(1–4)	(5–6)	(7–8)
Habitat	LEE, CE, CDWE	LEE, CE	LEE, CE, OSH
Boats	Cane rafts, dugout canoes	Cane rafts, dugout canoes	Dugout canoes
Nets	Vegetable fiber nets	Vegetable fiber nets	Throw nets
Hook and line	Cooper fish hooks	Present	Present
Traps	Wooden tapo, Shrimp trap[a]	Wooden tapo, Shrimp trap	Wooden tapo, Shrimp trap
Poisons	Ava seeds[b]	Ava seeds	Ava seeds
Other	Harpoons, bow and arrow	Harpoons	Harpoons
		Period	
		Contemporary Mexico	
	1910–1949	1950–1980	1981–present
	(9–10)	(10–15)	(10–15)
Habitat	LEE, CE, OSH	LEE, CE, OSH	LEE, CE, OSH
Boats	Dugout canoes	Dugout canoes, fiber glass skiffs with outboard motors, shrimp trawlers	Fiber glass skiffs, shrimp trawlers
Nets	Throw nets, gillnets, seine nets, cast nets	Throw nets, Intensification of gill-nets, seine nets and cast nets. Stationary tidal nets placed across the estuaries.	Throw nets, gillnets and seine nets and cast nets. Stationary tidal nets across estuaries.
Hook and line	Present	Present	Present
Traps	Wooden tapo, Shrimp trap	Wooden tapo, introduction of "concrete tapos," decrease of shrimp traps, fish and lobster traps[c]	Wooden tapos, concrete tapos, shrimp traps rare or unknown, fish and lobster traps.
Poisons	Ava seeds	Ava seeds	Cyanide, Ava seeds
Other	White handkerchief tied to a rock which evolved into a large wooden fish both used as bait to harpoonfish.	Harpoons, large wooden fish used as bait, Early use of pork meal[d]	Pork meal use intensifies.

*Note.*Habitat: lagoon-estuarine ecosystem (LEE), Coastal Ecosystem, (CE), Coastal Deep Water Ecosystem (CDWE), Offshore (OSH). Nets: throw net (atarraya), gillnets and seines (chinchorros), cast net (suripera). (1) Beals, 1932; (2) Edwards, 1969; (3) Meighan, 1969; (4) Mountjoy, 1969, 1970; (5) La Mota y Escobar, 1602–1605, reprinted 1940; (6) Lázaro de Arreguí, 1621, reprinted 1946; (7) Escudero & Hernández, 1849, reprinted 1997; (8) Cumbaa, 1973; (9) McGoodwin, 1973, 1980; (10) Wing, 1969; (11) Díaz& Iturbide, 1985; (12) García-Carmona, 2002; (13) Beltrán & Retamoza, 2003; (14) Chapa-Saldaña, 2007; (15) Fisher interviewed at San Blas.

[a]Traps: shrimp trap cylindrical wicker trap with a narrow mouth on one end.

[b]Fish and lobster traps cylindrical or rectangular made of wood or metal.

[c]Poisons: ava seeds *from Hurapolyandra* which contains diterpene an organic compound that can be used as a piscicide.

[d]Other: pork meal commercially available pork feeds. Sources given below time period.

Table 4. Quotes Showing Decreased Fishery Resource Abundance Over Time.

Year	Quote	Site
1621	In the coast of New Galicia mullets, snooks, snappers, shrimp, oyster and sleepers are very common. There are many turtles huge in size, and many genera of fish, swordfish and whales. In the river mouths there are plenty caimans and alligators. In the islands near the coast there are abundant sea lions (1).	NG
1849	The existence of immense uncultivated lands, dense forests, high mounts, and a great number of mighty rivers, makes the hunting, fishing, livestock and agricultural production in Sonora and Sinaloa very abundant (2).	NG
1935	In "El Conchal" estuary there were mullets, snooks, snappers, sea turtles, many oysters, even sharks and everything has been spoiled. Who spoiled everything? The government (3).	SB
1960	In the plaza large quantities of shrimp were sundried, today you can find shrimp only in the aquaculture farms, besides today what is spoiling everything in the environment and in the fisheries? The shrimp farms (4).	SB
1968	Because of overexploitation the government had placed a general moratorium on harvesting oysters shortly before these, they were all lost in the flood of 1968 (5).	MN
1980	A mangrove branch would fall into the water, and you could see large amounts of snappers, snooks and sea basses. Today nothing, at all, of that is over (6).	MN
1998	We are very poor here. The economic crisis is hitting us so hard that there are times in which we have nothing to eat. The fishing is gone and the land is no longer productive. Both men and women need to work for income (female agricultural wage worker) (7).	SS
2011	Without purina (pork meal) you cannot catch shrimp, is a necessity nowadays (8).	MN

*Note.*Sites: NG (New Galicia) Spanish colonial administrative region presently comprising the states of Jalisco, Nayarit and Southern Sinaloa; SB (San Blas), MN (Marismas Nacionales) includes southern Sinaloa and northern Nayarit; SS (Southern Sinaloa). Sources given next to quote.
(1) Lázaro de Arreguí, 1621, reprinted 1946; Escudero & Hernández, 1849 reprinted 1997; (3) Fisher interviewed at San Blas (91 years old); (4) Women fisher interviewed at San Blas (85 years old); (5) McGoodwin, 1973; (6) Fisher interviewed at Boca de Camichín (age mid 40's); (7) Cruz-Torres, 2001; (8) Fisher interviewed at Marismas Nacionales.

as a beautiful vision, recording the diversity of fauna the ocean harbors: oysters, shrimp, and fish such as mojarras (Gerreidae), mullets (Mugilidae), pompanos (Carangidae), sea basses (Serranidae), snooks (Centropomidae), snappers (Lutjanidae), rays (probably Myliobatidae, Rhynobatidae), and sharks (probably Carcharhinidae, Sphyrnidae; Appendix 2). Abundant catches could fail if large sharks and crocodiles were caught behind the weir. These would break the structure with their caudal fins and liberate the catch. Along San Blas coasts, sea turtles, turtle meat, and eggs were consumed and highly prized by natives (Láazaro de Arregui, 1621 [1946]).

Several natural history expeditions took place during the 18th century, including the Botanical expedition to the New Spain (1787–1791), which explored the coastal area of New Galicia. The detailed descriptions of fauna from this expedition gives evidence of Marismas' boundless resources (Mociño, Sessé, Echeverría, & Dios, 2010a, 2010b). San Blas estuaries were highly navigable with open mouths connecting to the Pacific Ocean and abundant with fish (AGI, 1786; Bernabéu, 1994).

Mexico's Independent Period (1810–1909)

The 19th century brought lingering conflicts to Marismas related to the movement toward independence (1810–1821), and the American (1846–1848) and French invasions (1864–1867) to the port of Mazatlán (Buelna, 1877). Although Mazatlán is north of Marismas, the social events at that time impacted Marismas inshore fisheries due to newcomers interested in fisheries commercialization arriving with the expanding trade in Mazatlán. This was motivated by new polices that declared fisheries open access in 1811 (Departamento de la Estadística Nacional, 1928). Mestizos also settled near the coastal plain, primarily producing smoked oysters and salted shrimp for trade to central Mexico (McGoodwin, 1979).

Fisheries in the mid-19th century were bountiful, with immense oyster banks and abundant shrimp (Escudero & Hernández, 1997). Shrimp were caught using fixed structures called "tapos," constructed wooden piles placed at the sea bottom across estuary channels. In between these tapos was a woven mat of mangrove branches creating a barrier. While this allowed water to pass, post-larval and juvenile shrimp, which feed in the lagoons and estuaries, were held back (Schafer, 1971).

In late 19th century, Asian traders discovered the abundant shrimp and oysters in Marismas' wetlands, and subsequently initiated oversea commercialization of seafood to the United States and Japan (McGoodwin, 1979). This foreign exploitation was carried out by small privately owned companies with government permits enabling access to a few, very productive, tapos. However, these permits were nullified after the revolution in 1911. While sufficient data to determine if shrimp were overexploited during this time is lacking, McGoodwin (1987) suggests this was unlikely, given that both the operating companies and local populations were small. Indeed, Marismas coasts were portrayed as desolated (Departamento de la Estadística Nacional, 1928; Figure 2(a)).

The population of San Blas had been declining since 1822, as the port of Mazatlán gained importance. San Blas estuaries harbored plentiful fish, oysters, and shellfish, and the coastal area had abundant pearls and large sharks and rays (Escudero & Hernández, 1997). By 1872, Mexico established a tax system for foreign fleets fishing offshore. But, open access continued for inshore fisheries (Buelna, 1877).

Contemporary Mexico

Period 1910 to 1949. By the early 20th century, cultivation of tobacco became a main economic activity of Marismas coastal ejidos (Mackinlay, 1998). Ejidos are collectively owned land, established throughout the 1930s by Mexico's agrarian revolution (Yetman, 2000). For inshore fisheries, the post-revolutionary reforms (1911–1913) declared inshore shrimp an open access resource for subsistence fishing (Secretaría de Pesca, 1991).

By 1930s, the wetlands of Marismas were decreed a national patrimony. The government bought the few remaining private fishing companies and established inshore fishing cooperatives under the federal law "Ley Federal de Cooperativas" (Diario Oficial de la Federación, 1933). This aimed to improve and protect the welfare of fishers by establishing exclusive exploitation of reserved species: shrimp, oysters, grouper, cabrilla, totoaba, abalone, lobster, and sea turtles (Covantes-Rodríguez & Beraud-Lozano, 2011; Márquez, 1996).

Early fishing cooperatives accepted everyone who was willing to join and soon accomplished the government target of increasing food production and extracting income from shrimp export. Meanwhile, free fishers practiced subsistence fishing and were not enrolled in cooperatives. They nonetheless coexisted harmoniously with the cooperatives, mainly because fisheries were then perceived as inexhaustible (McGoodwin, 1980) This perception was due to the presence of numerous corvinas (Sciaenidae), groupers (Epinephelidae, Serranidae), jacks (Carangidae), snappers (Lutjanidae), and snooks (Centropomidae; Wing, 1969; Table 4). In Teacapán, a prosperous shark fishery grew in response to the demand for shark liver oil during World War II (McGoodwin, 1973).

By the late 1940s, inshore fishing cooperatives were facing conflicts since they evolved in a strongly centralized environment, where the commercialization of their products strongly depended on the government's packing plants. In addition, throughout the 1940s, political-economic bossing afflicted Mexico's collective systems (which included fishing cooperatives) and for inshore fisheries, this lead to large shrimp smuggling throughout Marismas (McGoodwin, 1987). Mexico began fisheries exploitation in offshore waters, in the absence of the Allies' fleets during and after World War II, and created offshore shrimp-fishing cooperatives (Covantes-Rodríguez & Beraud-Lozano, 2011).

Period 1950 to 1980. Monocultures flourished in Sinaloa and Nayarit (1940–1970). Rural peasants worked for meager wages in low-grade agricultural fields and explored fishing for subsistence and extra income (Cruz-Torres, 2001), on grounds that were exclusive for cooperatives. This practice induced significant conflicts (McGoodwin, 1987), that intensified when the government relocated inland rural peasants to coastal areas (1952–1958) in response to Mexico's agricultural crisis (Secretaría de Pesca, 1991). Meanwhile, Mexico's Pacific offshore fleet expanded from 50 to 500 trawlers from 1949 to 1955, and trawlers fished near Marismas coastal lagoons. This activity was suggested as a threat for the further reduction of finfish populations (Covantes-Rodríguez & Beraud-Lozano, 2011; Edwards, 1978).

The 1950s were characterized by a race to catch finfish (McGoodwin, 1973), aided by new fishing technologies including outboard motors, fiberglass skiffs, and nylon nets (e.g., gillnets), increasing the feasibility of catching large individuals (Table 3). Consequently, higher trophic level (TL) finfish (snooks, groupers, and snappers) were decimated, while the shark fishery revived in Teacapán and newly paved roads aided shark product commercialization (McGoodwin, 1980). By early 1960s, inshore fishing cooperatives faced reduced shrimp production and fisher overcrowding. Exacerbating this issue, severe floods of late 1960s and agricultural runoff containing pesticides decimated many oyster banks of Sinaloa (Departamento de Pesca, 1978).

The productive estuaries of San Blás in the 1960s had bountiful fisheries, including large populations of olive ridley sea turtles (*Lepidochelys olivacea*), of which hundreds were killed weekly in San Blas throughout 1960s to 1970s, quickly exhausting local populations (Mountjoy, 1974).

Early fisheries research advised increasing fishing effort in Marismas, dredging the silted estuaries, and opening an artificial channel to boost flow within the lagoon (Chapa-Saldaña, 1966). Consequently, the Canal de Cuautla opened in 1975 and connected the Agua Brava lagoon-estuarine system to the Pacific Ocean (Flores-Verdugo et al., 1997).

Meanwhile offshore cooperatives increased shrimp exports, and accelerated fishing effort reduced shrimp landings in the late 1960s (Snyder-Onn & Brusca, 1975). To assure future production, a shrimp-fishing ban was established in the summer when shrimp larvae migrate from the sea into the lagoons. The offshore cooperatives could reduce the ban (June–September) depending on catch from the previous year, but this was inaccessible for the inshore cooperatives ban (April–August). In combination with government lack of support toward inshore fishing cooperatives, this created an ever-present conflict between the offshore and inshore sectors. By the 1980s, Mexico's economic crisis forced the country to join international lending plans in exchange for establishing market-oriented reforms (Vasquez, 1996). Then, the offshore shrimp cooperatives were debt-ridden. The country reshaped the fisheries law (Ley de Pesca) to privatize offshore shrimp, but these changes negatively affected the long-term rights of inshore fishers (Vásquez-León, 1994).

Period 1981 to present. Changes to Mexico's fisheries law throughout the 1980s and1990s privileged the growing private offshore shrimp industry and aquaculture shrimp farms. New reforms switched the inshore cooperatives to a fishing permit system and reduced their historical fishing area from 10 to 5 miles offshore. Proliferation of individuals without fishing tradition was facilitated by ensuing government turmoil (Diario Oficial de la Federación, 1997; Vásquez-León, 1994), exploiting resources heavily, and using more damaging gear than traditional users (Vásquez-León & McGuire, 1994).

The increased fishing effort was additionally maintained by organized rule-breaking systems (e.g., the shrimp black market), driven by the subsistence need of the fisher's population (Vásquez-León & McGuire, 1994). Conflicts also arose in inshore fishing grounds historically used by cooperatives because of the withdrawal of shrimp post-larvae by the shrimp aquaculture farms (Chapa-Saldaña, 2007). These became popular with the advancement of fisheries privatization (Berlanga-Robles, Ruiz-Luna, Bocco, & Vekerdy, 2011). The later events at Marismas exemplify how the country transitioned toward the "commodification of nature" (see Carothers & Chambers, 2012; Dhandapani, 2015; Washington, 2012). This was driven by the neoliberal capitalistic politics the Mexican government strongly embraced since the 1980s. For Marismas, shrimp fisheries and water resources (used for intensive agriculture in Sonora and Sinaloa) were a commodity with a historic importance given their substantial economic revenues. The later placed these resources at the center of Mexico's early privatization policies.

Throughout this period, increasing fishing effort in San Blás decreased landings of primary species (snappers, groupers, and snooks), while catches of secondary species (sierra, small sharks, sea catfish, mullet, and mojarra) increased and gained widespread consumer acceptance (Robles-García, 1987). Early fisheries data are insufficient to plot trajectories of fishery resources, but field surveys results show that 80% of fishers acknowledged a reduction in fish diversity, size, and catches over the last decades (Figure 2(a)). Fishers report fish catches have decreased over 50% since their initial year of fishing (Figure 2(c) to (d)). When compared with the types of fish (families) consumed in the past, the diversity of resources has decreased substantially (Figure 4, Appendices 1 and 2). For example, the higher TL fish (groupers TL 4, snappers TL 4.1, and snooks TL 3.8) in Marismas catches are now substituted with landings of fish of lesser value or lower TL (sea catfish TL 3.6, mullets TL 2.1, mojarras TL 3.2, and sierras TL 4.4).

Marismas contemporary fishery production is primarily from shrimp (77% of total landings). Although landings from 2001 to 2009 remained steady (mean 2,934 tons, *SD* 943 tons), fishers report less catch than in previous decades (Figure 2(b) to (d)). Moreover, field surveys report that shrimp fishing is based on the illegal use of pork meal to aggregate individuals and on prohibited nets of small mesh size (Rubio-Cisneros, Aburto-Oropeza, & Ezcurra, 2012; Table 4; Figure 5). Fishing shrimp with pork meal illustrates how the high profitability of the shrimp fishery (US $5.7 million per year) promotes the use of unsustainable fishing practices to extract more than what the system can provide. It also demonstrates that Marismas historical productivity is decreasing, and raises questions of the long-term profitability of the shrimp fishery and the wetland's health (Appendix 4).

Currently no data exists regarding environmental damage caused by the use of pork meal, but runoff from agriculture and shrimp farms has already affected the ecology of the region (Blais, 2003; Figure 5). Shrimp farm infrastructure (channels, roads) also fragmented and disturbed ecological processes of Marismas wetlands (Berlanga-Robles & Ruiz-Luna, 2002, 2007; Páez-Osuna, Guerrero-Galvan, & Ruiz-Fernandez, 1999). Furthermore, faulty planning of the Canal de Cuautla increased the inlet's width from 30 m to 2 km wide through erosion. Consequently, the salinity, water flow, and inundation patterns have changed near the channel. As such, deforestation of mangroves and modification of fauna diversity impacted the well-being of fishers (Berlanga-Robles & Ruíz-Luna, 2002, 2007; Hernández-Guzmán, Ruíz-Luna, & Berlanga-Robles, 2008; Kovacs, 2000; Páez-Osuna et al., 1999; Appendix 5). Furthermore, dams and agricultural irrigation near Marismas reduced freshwater input yet continued estuarine sedimentation

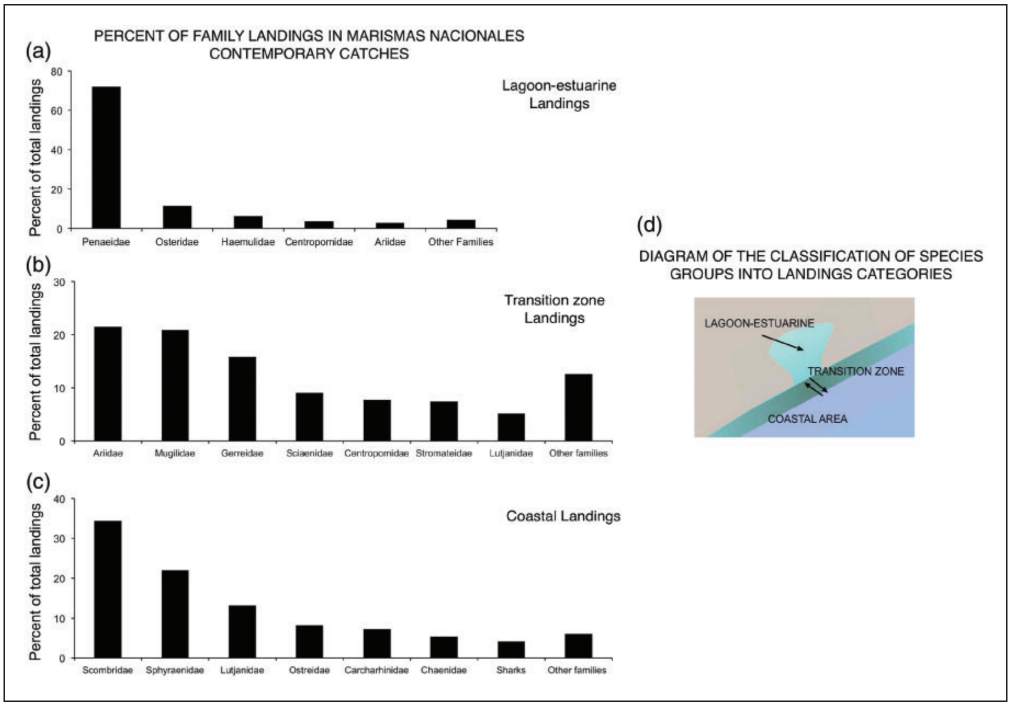


Figure 4. Percent of fisheries landings at Marismas Nacionales from 2001 to 2009 for families in the three different fishery resource categories: (a) Lagoon-estuarine (b) transition zone and (c) coastal. See Appendix 1 for landings values. (d) Spatial description of the different habitats used for the species groups classification.

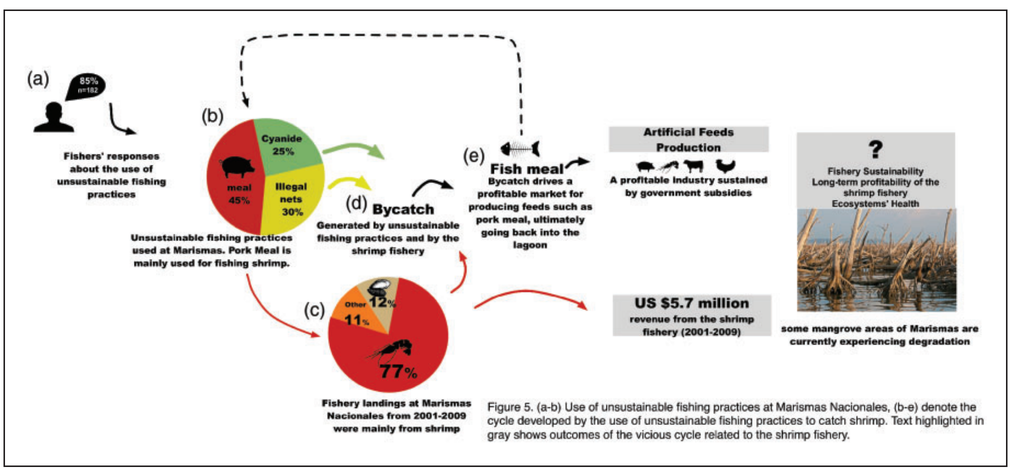


Figure 5. (a–b) Use of unsustainable fishing practices at Marismas Nacionales, (b–e) denote the cycle developed by the use of unsustainable fishing practices to catch shrimp. Text highlighted in gray shows outcomes of the vicious cycle related to the shrimp fishery.

(Hernández-Guzmán et al., 2008). Finally, fishers' responses to surveys revealed a litany of problems associated to long-term silting which has historically shattered productive fishing grounds.

Discussion

Pre-European societies at Marismas collected massive quantities of shellfish. Although data are scant, overexploitation of shellfish is suggested during the period of land abandonment in Marismas ~1300 A.D., a time that is also associated with changes in geomorphological processes (Shenkel, 1971). Archaeologists suggest that ecological outcomes of ancient nearshore fishing could mirror contemporary events of coastal exploitation (Torben & Erlandson, 2008), where some ancient societies were "fishing down the food web" (Pauly, Christensen, Dalsgaard, Froese, & Torres, 1998). For example, jacks and tunas were abundant in the Late Formative archaeological records in the state of Guerrero and their remains decrease in recent archaeological periods (Torben et al., 2008); while others were ‘‘fishing up the food web’’ (Torben & Erlandson, 2008). For example, tunas and sharks are documented only in more recent archaeological records (~1,500 years ago) at the Santa Barbara Channel, when plank canoes and toggled harpoons were introduced (Torben et al., 2008). Thus, negative changes in the abundance of shellfish populations in Marismas and probable modifications of inshore environments occurred early in history, before modern inshore fisheries coherent with patterns in other tropical latitudes (Cramer et al., 2012; Hardt, 2009; McClenachan, 2009).

Cultural context also matters when determining fishing pressure (Cinner, Marnane, & McClanahan, 2005). Jamaican finfish populations had an ancestral reprieve from harvesting during the Spanish occupation due to change in consumer preference to imported salted fish or beef (Hardt, 2009). Similarly, in Marismas, Spaniards preferred beef rather than fish, and the small coastal populations were only somewhat using marine resources (AGI, 1632, 1792), thus low fishing pressure existed for over three centuries.

The use of interdisciplinary data to study long-term coastal exploitation can also reveal how brief periods of accelerated fishing, coupled with changing population densities and varied fishing technologies, can reshape food webs (Hardt, 2009; Márquez, 1996; McClenachan et al., 2012). For example, fishing in the last 50 years reduced the mean size of ‘‘trophy’’ reef fish of recreational fishers in the Florida Keys from 19.9 to 2.3 kg (McClenachan, 2009). For Marismas, ‘‘fishing down the food web’’ in mid-20th century decimated higher TL fish and sea turtles like other nearshore areas around the Gulf of California (Sala et al., 2004; Torben et al., 2008). Fishing down the food web was driven by an increasing coastal population, changes in fishing technologies, and the global demand for shrimp consumption (Liedo et al., 2007; McGoodwin, 1987; Figure 3(c)).

Toward a Marine Protected Area in Marismas Nacionales

Our findings can help managers define recovery times for fish or shellfish populations and guide a marine protected area scheme for Marismas. This approach is timely given the failure of authorities to understand the importance of inshore fisheries for long-term sustainability in their exclusive focus on offshore fisheries (Vásquez-León, 1994). In other coastal areas of México, such as the Gulf of California, working examples of Marine Protected Areas (MPAs) exist. One is Loreto Bay National Park, where fishing is allowed and the no-take area is less than 1% of the park (Rife et al., 2013). The partial protection of this marine park has achieved limited recovery of reef fish populations, despite being protected for 15 years. However, ecosystem conditions have not further deteriorated since the park designation. Contrastingly, Cabo Pulmo National Park is another successful MPA, created in 1995, and is a complete commercial no-take area, made possible by the widespread support from the community. By 2009, total fish biomass in Cabo Pulmo increased by 463%, the largest recovery of any marine reserve worldwide (Aburto et al., 2011).

For Marismas, the fishers' ideas reported in our surveys suggest that the integration of bottom-up governance could help to reduce fishing effort and lead to a more stable social situation in the region, potentially paving way for the implementations of an MPA. For example, our interviews revealed awareness regarding the level of environmental degradation and adverse conditions of small-scale fisheries (e.g., increasing fishing effort, the environmental damage caused by unsustainable fishing gear). Some fishers were proactive about acquiring more sustainable options for their livelihoods. Several wanted to create artificial reefs, believing these would enhance fish populations. Others wanted to develop ecotourism enterprises and sustainable fish farms. Ironically, these intentions lack government support, and economic incentives for fishing continue in current fisheries policies. Studies in other fishing towns of Northwest Mexico suggest fishing effort can be ameliorated if the government recognizes fishing communities as key stakeholders and integrates them into policy design (Basurto et al., 2012; Cinti, Shaw, Cudney-Bueno, & Rojo, 2010; Cinti, Shaw, & Torre, 2010; Moreno-Báez, Orr, Cudney-Bueno, & Shaw, 2010). However, to develop an effective MPA for Marismas, this would need strong community leadership and effective enforcement, as exemplified by Cabo Pulmo's community. The later will be a challenge to Marismas, as the community maintains persistent problems with fishing enforcement and the strong commodification of fishery resources mainly given by the high profitability of shrimp sustains the continuation of legal and illegal fishing. Additionally, the current top-down structure in Mexico's fisheries limits the future sustainability of a MPA for Marismas coastal wetlands. Although the latest fisheries law enacted in 2007 Ley General de Pesca y Acuacultura Sustentables aimed to introduce fisheries decentralization, Mexico's inshore fisheries are still under the permit system, which is proven ineffective in reducing overfishing (Cinti et al., 2010; Cinti, Shaw, Cudney-Bueno, et al., 2010; Cisneros-Montemayor, Cisneros-Mata, Harper, & Pauly, 2013).

Sociocultural Traits of Marismas Nacionales

Sociocultural traits of fisheries are recently acknowledged in conservation planning (Cinner & Aswani, 2007;

Cochrane, Andrew, & Parma, 2011). These can enhance "social memory," which, in turn, influences social-ecological resilience. Social memory is obtained through the diversity of individuals and institutions within a community that draw on reservoirs of practices, knowledge, and values (Adger, Hughes, Folke, Carpenter, & Rockström, 2005). Our results hint at a loss of social memory throughout the history of Marismas. First, the natives were exterminated and their fishing traditions became a marginal activity, as perceived by the Spaniards. Much later, the organization of inshore fishing cooperatives built up social cooperation and a commitment toward fisheries. However, ignorance of sociocultural values of fishing communities arose when the fishing cooperatives' federations were dismantled and the reserved species rights ended, along with any appreciation of a social perspective for fisheries exploitation. Together with the influx of many new fishers, the fishing communities' social memory unraveled, and a cascade of illegal fishing behaviors prevailed (Figure 5).

Marismas fisheries exemplify Malthusian overfishing model where inshore fisheries have proliferated, driven by population growth in coastal areas coupled with governmental policies, forcing coastal inhabitants to fish more intensely and destructively for subsistence (Pauly, 2006). Consequently, Marismas' ecosystem evolved into a state where there is a reduced food web, sustained mainly by the shrimp fishery, caught with unsustainable practices.

The previous devolving processes are coupled to ineffective government responses to documented ecosystem change. For example, the overexploitation and further collapse of oyster banks in eastern North America (Kirby, 2004); and Jamaica's fishing on the outer reefs, preventing the recruitment of fish from these regions to aid in the recovery of near shore reefs (Hardt, 2009). For Marismas, the increasing fishing effort is mainly a consequence of México's policies toward the commodification of fisheries resources which largely enhanced fisheries development. The later magnified the ongoing inshore environmental degradation which was coupled to social conflict (Liedo et al., 2007). This sociopolitical pattern related to socioenvironmental issues associated to the commodification of nature occurred in many fishing towns of Latin America (Defeo & Castilla, 2012) and elsewhere throughout the late 20th century (e.g., fisheries privatization; Carothers & Chambers, 2012; Cambodia's dispossession of freshwater fisheries; Sneddon, 2007).

Implications for Conservation

Marismas is a hotspot of ecosystem services (e.g., biodiversity, fisheries, carbon sequestration) provided at different temporal and spatial scales (Rubio-Cisneros et al., 2014, 2016). Our results can assist managers in developing a robust picture of the wetland and can aid in creating initiatives that could modify current fisheries policies to be more inclusive of resource users themselves (e.g., fishers' traditional knowledge could be applied for the conservation of shrimp, finfish and oyster habitats). Although Mexico is internationally active in conservation matters, the destruction of coastal wetlands continues silently on local scales until the issue becomes international news (Vargas, 2016). As such, interdisciplinary baseline studies are needed at Marismas, these can help identify socioecological issues that need conservation priority. These studies can also help to understand how to prevent the further degradation of coastal ecosystem services that Marismas has historically provided to humans. Finally, this study can help managers in other countries where humans are facing conservation challenges related to depleted coastal food webs and information of wetlands exploitation is limited.

Appendix

Appendix 1. Total Fishery Landings From 2001 to 2009 at Marismas Nacionales.

	Family	Common name	Common name (Spanish)	Genus	Sum of Landings kg (2001–2009)
Lagoon-estuarine fishery resources	Penaeidae	estuarine shrimp	camaron de estero	*Litopenaeus*	26,605,071
		shrimp	camaron	*Litopenaeus*	3,082,130
		green shrimp	camaron verde	*Nd*	1,783
	Ostreidae	pleasure oyster	ostion de placer	*Crassostrea, Saccostrea*	4,679,621
	Haemulidae	grunt	burro	*Haemulon/ Anisotrmus*	2,546,15

(continued)

Appendix 1. Continued

	Family	Common name	Common name (Spanish)	Genus	Sum of Landings kg (2001–2009)
			mojarron	*Anisotremus*	280
			ronco	*Haemulon*	19,093
			mojarra prieta	*Haemulon*	
	Centropomidae	snook	constantino	*Centropomus*	1,435,915
			paleta	*Centropomus*	66,527
	Ariidae	sea catfish	bandera	*Bagre*	1,109,131
	Sciaenidae	croaker	berrugata	*Menticirrhus*	423,357
			boca dulce	*Menticirrhus*	565
	Tetradontidae	pufferfish	botete	*Arothron, Canthigaster, Sphoeroides*	422,306
	Gerreidae	mojarra	mojarra china	*Diapterus, Eugerres, Gerres*	192,709
			mojarra blanca	*Eucinostomu, Gerres*	126,648
			mojarra aleta amarilla	*Diapterus*	40,554
			mojarra plateada	*Eucinostomus, Diapterus, Gerres*	21,437
			mojarra pinta	*nd*	350
	Palaemonidae	prawn	moya	*Macrobrachium*	372,312
	Arcidae	mangrove cockle	almeja pata de mula	*Anadara*	127,352
	Albulidae	bonefish	macabi	*Albula, Elops*	23,620
	Portunidae	blue crab	jaiba	*Callinectes*	1,464
				Total landings	41,298,375
Transition zone Fishery Resources	Ariidae	sea catfish	Chihuil	*Bagre, notarius*	4,652,435
	Mugilidae	mullet	lisa	*Mugil*	1,821,070
			lisa macho	*Mugil*	533,243
			liseta	*Mugil*	2,178,163
	Gerreidae	mojarra	mojarra	*Eucinostomus, Diapterus, Gerres*	3,400,776
			mojarra malacapa	*Eugerres*	16
			mojarra mueluda	*Calamus*	50
			mojarra piedrera	*nd*	2,290
	Sciaenidae	corvina	corvina	*Cynoscion, Bairdiella*	1,358,218
			corvina graniza	*Cynoscion*	200
		croaker	chano	*Micropogonias, Umbrina, Menticirrhus*	543,224
			raton	*Menticirrhus*	59,816
	Centropomidae	snook	robalo	*Centropomus*	1,685,873
	Stromatidae	butterfish	chabelita	*Peprilus*	1613305
	Lutjanidae	mexican barred snapper	pargo coconaco	*Hoplopagrus*	83,859
		snapper	pargo	*Lutjanus*	1,017,265
		spotted rose snapper	pargo lunajero	*Lutjanus*	8,680
	Triakidae	hound shark	cazon	*Mustelus*	1,004,990
	Dasyatidae	ray	mantarraya	*Dasyatis, Myliobatis, Gymnura, Aetobatus*	714,843
	Carangidae	jacks	chile	*nd*	60,411
			jurel	*Caranx*	17,576
			monda	*Oligoplites, Chloroscombrus, Hemicaranx,*	3,624

(continued)

Appendix 1. Continued

	Family	Common name	Common name (Spanish)	Genus	Sum of Landings kg (2001–2009)
			palometa	*Oligoplites, Hemicaranx, Gnathanodon*	198,184
			pampano	*Caranx,Trachinotus*	132,744
	Haemulidae	grunt	bacoco	*Anisotremus, Haemulon*	129,330
			corcovado	*Orthopristis, Haemulopsis*	50
			roncacho	*Haemulopsis, Microlepidotus*	58,724
	Pinnidae	scallop	callo de hacha	*Atrina, Pinna*	132,547
	Osteridae	oyster	ostion	*Crassostrea, Saccostrea, Striostrea*	122,572
	Serranidae	grouper	cabrilla	*Mycteroperca, Epinephelus, Paralabrax*	2,237
			mero	*Epinephelus, Mycteroperca*	60,799
	Hemiramphidae	needle fishes	pajarito	*Hemiramphus, Hyporhamphus*	33,037
	Myliobatidae, Dasyatidae, Gymnuridae	ray	raya	*Myliobatus,Mobula, Rhinoptera,Dasyatis*	29,363
	Bivalvia	clam	almeja	*nd*	13,500
	Paralichthyidae	flatfish	lenguado	*Paralichthys,Bothus*	9,379
	Nemastistiidae	rooster fish	pez gallo	*Nematistius*	2,789
	Kyphosidae	chub	chopa	*Kyphosus, Girella, Hermosilla, Sectator*	550
	Penaeidae	blue shrimp	camaron azul	*Litopenaeus*	76
		shrimp caught offshore	camaron de alta mar	*Litopenaeus, Farfantepenaeus*	487
	Tetradontidae	pufferfish	tambor	*Sphoeroides*	577
	Rhinobatidae	guitar fish	pez guitarra	*Rhinobatos, Zapteryx*	92
				Total Landings	**21,686,964**
Coastal Fishery Resources	Scombridae	sierra	sierra	*Scomberomorus*	2,836,500
			barrilete	*Katsuwonus sp.*	83,476
		bonito	bonito	*Sarda, Auxis, Euthynnus*	5,159
			atun aleta amarilla	*Thunnus*	3,680
			atun aleta azul	*Thunnus*	80
	Sphyraenidae	barracuda	picuda	*Sphyraena*	1,870,957
	Lutjanidae	red snapper	guachinango	*Lutjanus*	1,089,384
		snapper	guachito	*Lutjanus*	30,792
			pargo joselillo	*Lutjanus*	3,211
			flamenco	*Lutjanus, Hoplopargus*	709
	Osteridae	rock oyster	ostion de roca	*Crassostrea, Saccostrea, Striostrea*	697,566
		requiem sharks	tiburon toro	*Carcharhinus leucas*	513,710
			tiburon volador	*Carcharhinus limbatus*	96,130
			tiburon tigre	*Galeocerdo cuvier*	35
	Chaenidae	milkfish	sabalo	*Chanos*	162,332
			sabalote	*Chanos*	289,840

(continued)

Appendix 1. Continued

	Family	Common name	Common name (Spanish)	Genus	Sum of Landings kg (2001–2009)
	Diverse shark families Alopiidae, Carcharhinida, Sphyrnidae, and other	Shark	Tiburon	*Nd*	351,937
	Myliobatidae	ray	gavilan	*Rhinoptera, Myliobatis, Aetobatus*	5,010
			manta	*Myliobatus, Mobula, Rhinoptera, Dasyatis*	98,192
	Ariidae	sea catfish	condor	*Bagre*	75,356
	Coriphaenidae	dolphinfish	dorado	*Coryphaena*	64,950
	Serranidae	grouper	baqueta	*Epinephelus, Hyporthodus*	54,081
			gallina	*Epinephelus*	1,027
			cardenal	*Paranthias*	1,016
			gallineta	*Epinephelus*	25
			verdillo	*Paralabrax*	550
	Sphyrnidae	hammerhead shark	tiburon martillo	*Sphyrna*	50,996
	Balistidae	triggerfish	bota	*Pseudobalistes, Balistes, Sufflamen*	35,665
			cochi	*Pseudobalistes, Balistes, Sufflamen*	17,885
	Carangidae	jacks	caballo	*Selene, Caranx*	1,918
			cocinero	*Caranx, Carangoides, Hemicaranx*	450
			indio	*Paranthias*	290
			ojoton	*Caranx, Trachurus, Decapterus, Selar*	1,371
			medregal	*Selar, Selene, Seriola,*	31,220
	Triakidae	hound shark	tiburon tripa	*Mustelus*	21,865
	Squatinidae	angel shark	tiburon angelito	*Squatina*	16,455
	Ophidiidae	cusk eel	lengua	*Brotula*	8,598
	Istiophoridae	billfish	marlin	*Makira, Tetrapturus, Kajikia*	100
			pez vela		7,600
	Palinuridae	lobster	langosta	*Panulirus*	5,960
	Scaridae	parrotfish	loro	*Scarus, Nicholsina*	193
	Haemulidae		perico	*Scarus*	3,126
			rasposa	*Haemulon*	2,433
	Malacanthidae	tilefish	conejo	*Caulolatilus*	960
			pierna	*Caulolatilus*	135
	Ginglymostomatidae	nurse shark	tiburon gata	*Ginglymostoma*	371
	Syngnathidae	pipefish	culebra	*Microphis*	533
	Ephippidae	spadefishes, batfishes and scats	mona	*Chaetodipterus, Parapsettus,*	300
	Labridae	wrass	vieja	*Bodianus*	119
	Muraenidae	morey eels	morena	*Muraena, Gymnothorax, Echidna*	125
				Total landings	**8,544,373**

Note. The different landings categories (lagoon-estuarine, transition zone, and coastal) are shown in the first column. Values were obtained from five local fisheries offices along Marismas Nacionales in the municipalities of Escuinapa, Tecuala, Tuxpan, Santiago Ixcuintla, and San Blas. Data were recorded by the Mexican National Commission of Fisheries and Aquaculture (CONAPESCA).

Appendix 2. Available Information Related to Main Food Items in Marismas Nacionales for Each Time Period.

Period: Pre-Columbian, 7000 B.C.–2500 B.C. (Archaic)	
Shellfish	
Family	Genus/Species
Arcidae	*Anadara* spp.
	Anadara grandis
	Anadara tuberculosa
Carditidae	*Cardita laticostata*
Melongenidae	*Melongena patula*
Muricidae	*Hexaplex brassica*
	Muricanthus nigritus
Osteridae	*Ostrea corteziensis*
Pectinidae	*Aequipecten circularis*
Veneridae	*Anomalocardia subrugosa*
	Chione gnidia
	Chione undatella
	Tivela byronesis

Appendix 2, continued. Pre-Columbian, 2500 B.C.–900 B.C. (Pre-Classic); Pre-Classic period information is available only for San Blas; the northern area of Marismas Nacionales was experiencing episodes of land abandonment.

Shellfish			**Fish**		**Crustaceans**			**Tetrapods**
Family	Genus/species		Family	Genus/ species	Family	Genus/species	Family	Genus/ species
	Carditidae	*Cardita laticostata*	Ariidae	Aridae spp.	Menippidae	*Menippe* sp.	Cheloniidae	*Caretta caretta*
	Calyptraeidae	*Cerpidula onyx*				*Chelonia mydas*		
	Pectinidae	*Aequipecten circularis*						*Eretmochelys imbricate*
	Melongenidae	*Melongena patula*						*Lepidochelys olivacea*
	Muricidae	*Muricanthus nigritus*					Pelecanidae	*Pelicanus occidentalis*
		Thais biserialis			Sulidae	*Sula* sp.		
	Osteridae	*Ostrea iridescens*					Ardeidae	*Florida caerulea*
		Ostrea Aff. Palmula					Cathartidae	unknown genus

Sources for both tables: Shenkel (1971, 1974), Foster and Gorenstein (2000), Mountjoy (1970, 1974), Feldman (1976); Mountjoy and Claassen (2005), Cumbaa (1973).

Appendix 2, continued. Pre-Columbian, 200 A.D.–900/1000 A.D. (Classic).

Shellfish		**Fish**		**Sharks and rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/ species	Family	Genus/species	Family	Genus/species
		Ariidae		Charcharhinidae	*Galeocerdo cuvieri*	Crocodylidae	*Crocodilus acutus*
Arcidae	*Anadara grandis*	Clupeidae			*Carcharhinus* spp.		
		Carangidae	*Trachinotus* sp.				
Osteridae	*Ostrea corteziensis*	Centropomidae					
Pectinidae		Elopidae					
Melongenidae		Gerreidae					
Muricidae		Haemulidae	*Pomadasys* sp.				

(continued)

Appendix 2, continued. Continued

Shellfish		**Fish**		**Sharks and rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species
		Ariidae		Charcharhinidae	*Galeocerdo cuvieri*	Crocodylidae	*Crocodilus acutus*
		Lutjanidae					
		Mugilidae					
		Sciaenidae					
		Serranidae					
		Sparidae					

Appendix 2, continued. Pre-Columbian 1000 A.D.–Spanish contact (Post-Classic).

Shellfish Family	Genus/species
Arcidae	*Anadara grandis*
	Anadara tuberculosa
Melongenidae	*Melongena patula*
Muricidae	*Hexaplex brassica*
	Muricanthus nigritus
Olividae	*Agaronia propatula*
Osteridae	*Ostrea corteziensis*
Naticidae	*Natica* sp.
Turritellidae	*Turritella gnostoma*
	Turritella leucostoma
Veneridae	*Anomalocardia subrugosa*
	Chione gnidia
	Tivela byronesis

Sources for both tables: Shenkel, 1971, 1974; Foster & Gorenstein, 2000; Mountjoy, 1970, 1974; Feldman, 1976; Mountjoy & Claassen, 2005; Cumbaa, 1973.

Appendix 2, continued. Spanish Occupation 1523–1810.

Shellfish		**Fish**		**Crustaceans**		**Sharks and Rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species
Osteridae	*Ostrea spp.*	Carangidae	*Trachinotus* spp.	Penaeidae	*Farfantepenaeus* spp.	Charcharhinidae	*Galeocerdo cuvier*	Cheloniidae	*Caretta caretta*
		Centropomidae	*Centropomus* spp.	*Litopenaeus* sp.	*Carcharhinus* spp.		*Chelonia mydas*		
		Gerreidae	*Eucinostomus* spp.		*Alopias sp.*	*Eretmochelys imbricate*			
		Lutjanidae	*Lutjanus* spp.		Sphyrnidae	*Sphyrna lewini*	*Lepidochelys olivacea*		
		Mugilidae	*Mugil* spp.		Dasyatidae	*Dasyatis* sp.	Crocodylidae	*Crocodilus acutus*	
		Serranidae	*Ephinephelus* spp.	Myliobatidae	*Myliobatis* sp.				
		Xiphiidae	*Xiphias sp.*			*Mobula* sp.			
		Eleotridae	*Dormitator latifrons*	Rhynobatidae	*Rhinobatus* sp.				

Sources: La Mota y Escobar, 1602–1605, reprinted 1940; Lázaro de Arreguí, 1621.

Appendix 2, Continued. Mexico's Independent Period 1810–1909.

Shellfish		**Fish**		**Crustaceans**		**Sharks and Rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species
Osteridae	*Ostrea spp.*	Centropomidae	*Centropomus* spp.	Penaeidae	*Farfantepenaeus* spp.	Charcharhinidae	*Galeocerdo cuvier*		
		Lutjanidae	*Lutjanus* spp.	*Litopenaeus* sp.	*Carcharhinus* spp.				
		Serranidae	*Ephinephelus* spp.	Dasyatidae	*Dasyatis* sp.				
		Sciaenidae	Cynosion spp.		Myliobatidae	*Myliobatis* sp.			
						Rhynobatidae	*Mobula* sp.		
							Rhinobatus sp.		

Sources: Buelna, 1877; McGoodwin, 1973, 1979, 1980.

Appendix 2, Continued. Mexico's Contemporary 1910–1949.

Shellfish		**Fish**		**Crustaceans**		**Sharks and rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species
Osteridae	*Ostrea spp.*	Epinephelidae	*Mycteroperca* sp.	Penaeidae	*Farfantepenaeus* spp.	Charcharhinidae	*Carcharhinus* spp.	Cheloniidae	*Caretta caretta*
			Epinephelus spp.,	*Litopenaeus* sp.	*C. limbatus*	*Chelonia mydas*			
Haliotidae	*Haliotis* sp.		Palinuridae	*Panilurus* sp.	*C. obscurus*	*Eretmochelys imbricate*			
		Carangidae	*Caranx* sp.			*Galeocerdo cuvieri*			*Lepidochelys olivacea*
			Caranx caballus		*Rhizoprionodon longurio*				
			Gnathanodon speciosus,	Lamnidae	*Carcharodon carcharias*				
			Oligoplites sp.	Triakidae	*Mustelus lunatus*				
			Selene sp.	Sphyrnidae	*Sphyrna lewini*				
			Seriola sp.						
			Trachinotus sp.						
		Centropomidae	*Centropomus* spp.						
			Centropomus robalito						
		Sciaenidae	*Cynoscion macdonaldi*						
		Serranidae	*Paralabrax* spp.						
		Lutjanidae	*Lutjanus* spp.						
			Lutjanus peru						
			Lutjanus argentiventis						

Sources for both tables: Inskeep, 1961; Wing, 1969; Covantes-Rodríguez & Beraud-Lozano, 2011; Secretaría de Marina, 1952, 1954; García-Carmona, 2002.

Appendix 2, Continued. Mexico's Contemporary 1950–1980.

Shellfish		**Fish**		**Crustaceans**		**Sharks and rays**		**Tetrapods**	
Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species	Family	Genus/species
Osteridae	*Ostrea spp.*	Carangidae		Penaeidae	*Farfantepenaeus* spp.	Charcharhinidae	*Carcharhinus* spp.	Cheloniidae	*Lepidochelys olivacea*
	Ostrea corteziensis	Centropomidae			*Litopenaeus* sp.				
Haliotidae	*Haliotis* sp.	Lutjanidae							
		Serranidae							
		Sciaenidae							

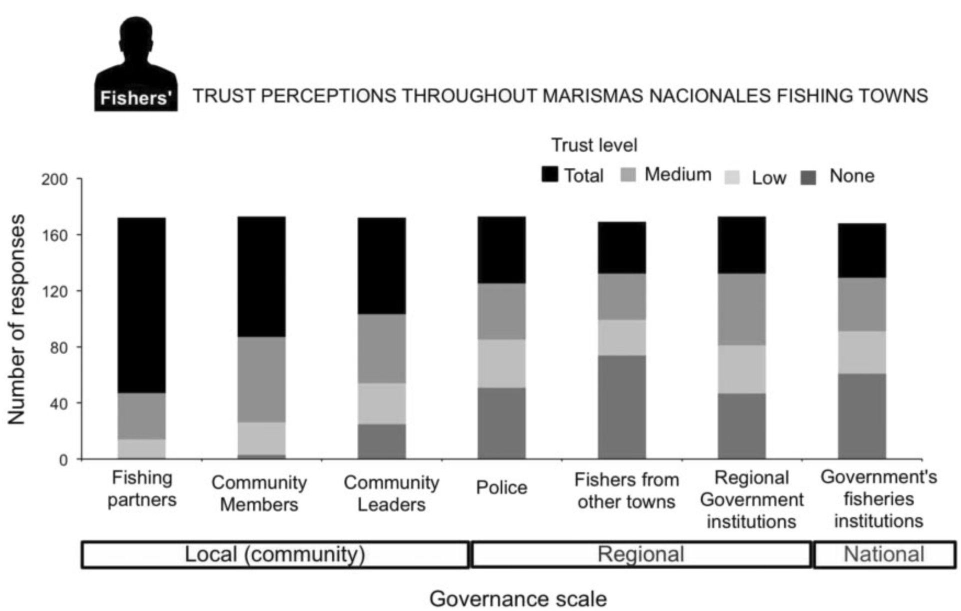
Note. For data about fisheries exploitation from 1981 to the present see Appendix 1. Information belongs to data collection from interdisciplinary literature sources.
Source: Inskeep (1961), Wing (1969), Covantes-Rodríguez and Beraud-Lozano (2011), Secretaría de Marina (1952, 1954), García-Carmona (2006).

Appendix 3. Number of Shellfish in Some 628 Shellfish Middens and Mounds Distributed Throughout the Teacapán Estuary at Marismas Nacionales (see Figure 1).

Type	Species	Estimated number
Oyster middens ($n = 558$)		
	Ostrea corteziensis	972×10^6
Tivela middens ($n = 20$)		
	Tivela byronesis	102×10^6
	Agaronia propatula	4.6×10^5
	Natica sp.	17.7×10^5
	Turritella gnostoma	9×10^5
	Turritella leucostoma	8×10^5
	Anadara grandis	2×10^5
Linear shell mounds ($n = 48$)		
	Ostrea corteziensis	5.32×10^9
A. grandis mounds ($n = 2$)		
	Anadara grandis	2.3×10^9
	Muricanthus nigritus	351×10^6
	Anomalocardia subrugosa	339×10^6
	Ostrea corteziensis	304×10^6
	Chione gnidia	199×10^6
	Anadara tuberculosa	47×10^6
	Hexaplex brassica	47×10^6
	Melongena patula	47×10^6

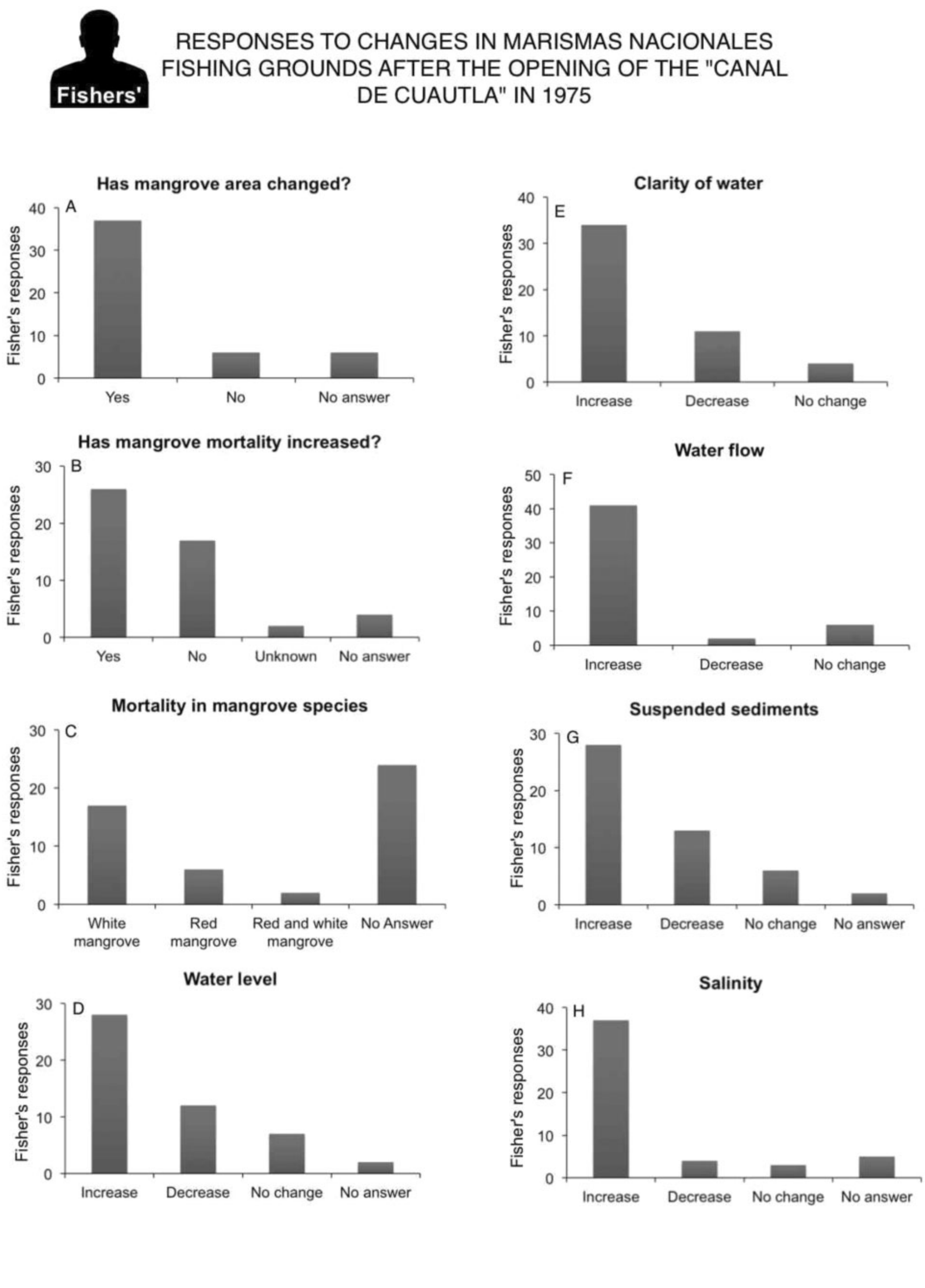
Note. Shellfish values were estimated by Shenkel (1971).

Appendix 4. Fishers' Responses to Field Interviews Regarding Changes to Fishing Grounds After the Opening of the Canal de Cuautla



Note. (a) Changes in mangrove area since the opening of the channel; (b) mangrove mortality after the opening of the channel; and (c) mortality in mangrove species. Fisher's responses to changes in water physical properties since the opening of the channel: (d) water level; (e) clarity of water; (f) water flow; (g) suspended sediments; and (h) salinity.

Appendix 5. Results From Fishers' Interviews About Their Trust Perceptions of Institutions With Different Governance Scales



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